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16. ABSTRACT

EPA has been involved for several years in developing and demonstrating methods for the control, recycle, and destruction of water pollutants generated in the electroplating and related industries. This paper examines a number of the newer technologies, describes applications in which EPA's R&D program has been involved and presents cost figures generated as the result of these studies. All EPA projects are referenced so that the reader can pursue those of particular interest in greater detail.

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The following information concludes a summary of the latest techniques being developed to eliminate or minimize discharges of the primary pollutants of the electroplating industry. Most of the results presented in this issue are derived from EPA-co-sponsored research projects, and cover such areas as reverse osmosis, electrodialysis, membrane techniques, solvent-based systems and freezing.

". . . our work has attempted to address the most pressing problems, as reflected by the industry, its associations and its suppliers—all of whom are, in the final analysis, the sources of most of the technology."

By Herbert S. Skovronek & Mary K. Stinson

REVERSE OSMOSIS

Reverse osmosis has been under development for several years. To date, EPA has completed several projects on reverse osmosis under grants to the American Electroplaters' Society, Inc. (AES) with North Star Research Institute Abcor, Inc., and Celanese Research Company as contractors.[28-33] EPA and AES continue to support new projects in this area.

The use of selectively permeable membranes makes it possible to concentrate rinsewater pollutants in their "as-is" chemical form while simultaneously generating an effluent stream (the permeate) which is relatively free of pollutants. The permeate can then be discharged or reused in the process, while the concentrated pollutants (concentrate) can be returned to the plating bath, used as the feed stream for evaporative concentration, or treated more effectively and economically by chemical means. Since no chemicals are added and the wastewater undergoes no phase change, the process does not produce any sludge and is low in energy consumption. Other advantages can also be cited for RO:

- **Low capital cost.** The modular nature of RO units makes them particularly well-suited for small-scale installations.
- **Low space requirements.** RO equipment is compact and operates continuously requiring minimal tankage.
- **Low labor cost.** The process is simple to operate and fully automated, requiring little operator attention. Based on these advantages, reverse osmosis, alone or coupled with an evaporator where needed, is recognized as a preferred separation technique for closed-loop recovery systems. The installation to date of about two hundred RO systems for plating waste treatment indicates that the plating industry recognizes the advantages of RO.[34-36] Most of these applications are for nickel rinsewaters.

Two problems which have inhibited the use of RO for plating wastes other than nickel are changing pH and presence of oxidizing substances (chlorine, chromic acid). The commercially available RO membranes operate within the pH range of 2.5 - 11 (cellulose acetate 2.5 - 7; DuPont polyamide 4 - 11). As the wastes are concentrated, the pH of the concentrate can rise to above 11 (alkaline cyanide baths) or below 2.5 (acid chromium). Under these circumstances, most commercially available membranes rapidly deteriorate.

Some examples of the cooperative EPA-AES research, development, and demonstration program for the use of RO for the treatment of plating rinsewaters are highlighted in the following paragraphs.

Commercially available membranes were pilot plant tested at Walden Research, a Division of Abcor, Inc., Wilmington, MA, to determine their applicability for treating various plating rinsewaters. Emphasis was placed on closed-loop operation with recycle of purified water for rinsing and return of plating chemical concentrate to the bath. Three commercially available membrane configurations were evaluated experimentally: tubular (cellulose acetate membrane), spiral-wound (cellulose acetate membrane) and hollow-fiber (polyamide membrane). Tests were conducted with nine different rinse waters prepared by dilution of actual plating baths. Advantages and limitations of the reverse osmosis process and specific membranes and configurations are discussed and summarized in Table II (taken from the report).

TABLE II
EVALUATION OF RO FOR SYSTEMS TESTED

Attractive Systems	*Limitations*
Watts-Type Nickel	Boric acid selectively permeates membranes
Nickel Sulfamate	Boric acid selectively permeates membranes
Copper Pyrophosphate	Possible decomposition of pyrophosphate
Nickel Fluoborate	Boric acid selectively permeates membranes
Zinc Chloride	Need evaporation to close loop
Copper Cyanide	Need low-pH bath for current membranes
Zinc Cyanide	Need low-pH bath for current membranes; need evaporation to close loop
Cadmium Cyanide	Need low-pH bath for current membranes; need evaporation to close loop
Unattractive Systems	*Limitations*
Chromic Acid	Attacks and destroys all membranes unless neutralized
Very-high pH Cyanide Baths	Attacks and destroys all membranes commercially available; newer membranes under development show promise for treating high-pH cyanide baths

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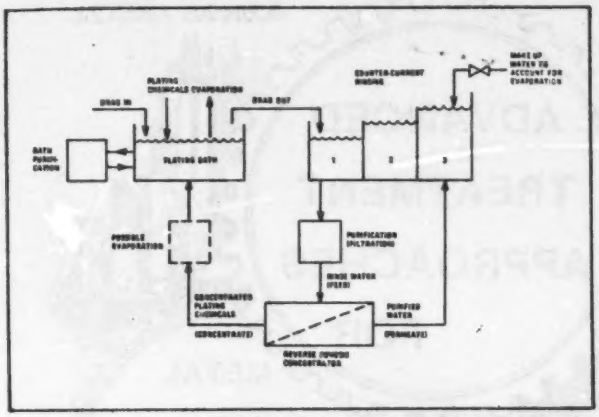
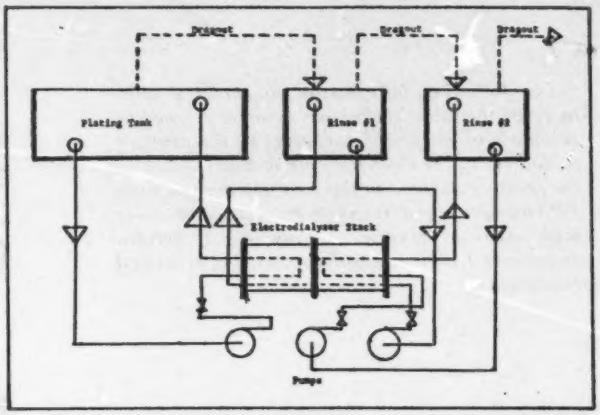


Flow schematic for RO at Walden Research, Wilmington, MA.



A schematic of a commercial electrodialysis system for cyanide recovery.

Several field tests were conducted to demonstrate closed-loop treatment with conventional RO membranes. One field test at the New England Plating Co., Worcester, MA demonstrated that the DuPont polyamide membrane could be successfully used to recover Watts-nickel rinsewaters.[31] Two other field tests were conducted at Whyco Chromium Co., Thomason, CT and New England Plating Co., Worcester, MA to evaluate the treatment of copper cyanide rinsewaters, but the rate of membrane deterioration (because of the high pH level) was too rapid to make this application an economically attractive one.[32]

Work on several new polymer matrices has also been carried out to expand the applicability of RO to other plating baths of major importance.[28,33] Tests with a new NS-100 membrane (North Star's cross-linked polyethylene imine) demonstrated its sustained performance with highly acidic (pH 1) and highly alkaline (pH 13) metal finishing wastewaters. However, further research is needed to optimize the fabrication of tubular and spiral wound configurations using this membrane.[29]

A laboratory research project has also been carried out to develop a PBI (polybenzimidazole) membrane for the treatment of acidic chromium plating rinses.[33] The study demonstrated that the polymer, cast into a flat sheet, is indeed chemically and physically resistant to chromic acid. Unfortunately, at this stage of development, the PBI membrane maintains high rejections to chromic acid only for a very short time. Further research is needed to improve the RO properties of PBI membranes.

Pilot plant testing of several newly developed and laboratory pretested membranes is nearing its completion under EPA Grant No. 804311. The results of these tests, performed at Walden, are highly encouraging for three new membranes:

- PA-300 (polyamide composite membrane) from. Fluid Systems Division of UOP, San Diego, CA;
- PBIL (polybenzimidazolone) from Teijin Ltd., Tokyo, Japan;
- NS-100 (polyethylene imine) from Abcor, Inc., Wilmington, MA.

One or more of these membranes exhibits excellent performance and little or no degradation at pH's of >13 and <1 and in chromic acid rinsewaters. The PA-300 membrane is also being evaluated on-stream for treatment of zinc cyanide rinsewater under EPA Grant No. 803753.

The most recent EPA/AES RO project is a field demonstration with a "mobile" system under EPA Grant No. 805300. The mobile system will be skid-mounted and will consist of the most promising membranes (probably PA-300 and PBIL) and a small evaporator. Two field demonstrations of six month duration on rinsewaters of major importance such as zinc cyanide, chromic acid or acid copper, will be performed under this project. Both PA-300 and PBIL membranes are close to commercialization. If the mobile system demonstrates their performance on-stream, it will be a major breakthrough in expanding the application of RO to the recovery of diverse plating rinsewaters.

ELECTRODIALYSIS

Electrodialysis is also a membrane technique which has been of some interest to EPA over the years.[37] By imposing an electrical potential across a cell in which the ions are contained within a cell bounded on one side by a membrane permeable only to cations and on the other by another membrane permeable only to anions, a plating wastewater can be made to separate into a cation- (or metal ion) rich wastewater and an anion- (or cyanide ion) rich wastewater. By passing the same wastewater sequentially past both anion and cation permeable membranes while the electrical potential is applied, the contaminants can be concentrated in one stream while the original rinsewater is freed of pollutants and made acceptable for discharge. The concentrate can, as with RO, then be recycled to the process or chemically treated for disposal.

A project recently carried out under EPA sponsorship (Grant No. 803742) at Risdon Mfg. Co., Waterbury, CT demonstrated this technique in successfully recovering nickel by achieving over 100-fold concentration of rinsewater originally containing up to 1 g/l of nickel.[38] Extrapolated costs for full scale operation of this system indicate savings on recovered nickel alone of $13,451 per year. Total savings on nickel salts, destruct chemicals, sludge disposal and brighteners have been estimated to be $16,421/yr., or $68/day. Estimated payback in most cases should be 18 months or less, even if based on recovered nickel salts alone.

Full-scale trials of electrodialysis to close the loop on plating cyanide rinsewaters were also conducted under an EPA grant at the Keystone Lamp Manufacturing plant, Slatington, PA.[39] Unfortunately, the full-scale system was only about one-fourth as effective as that achieved earlier on synthetic sodium copper

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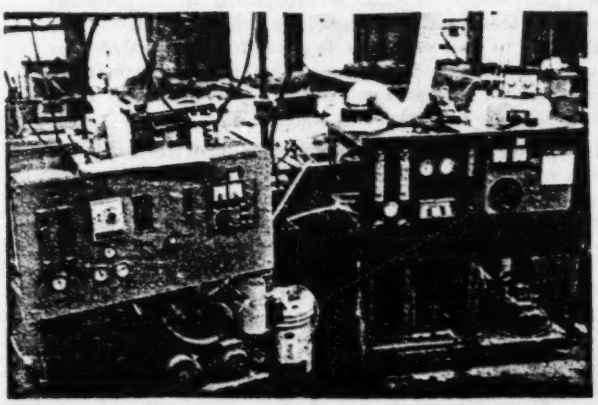
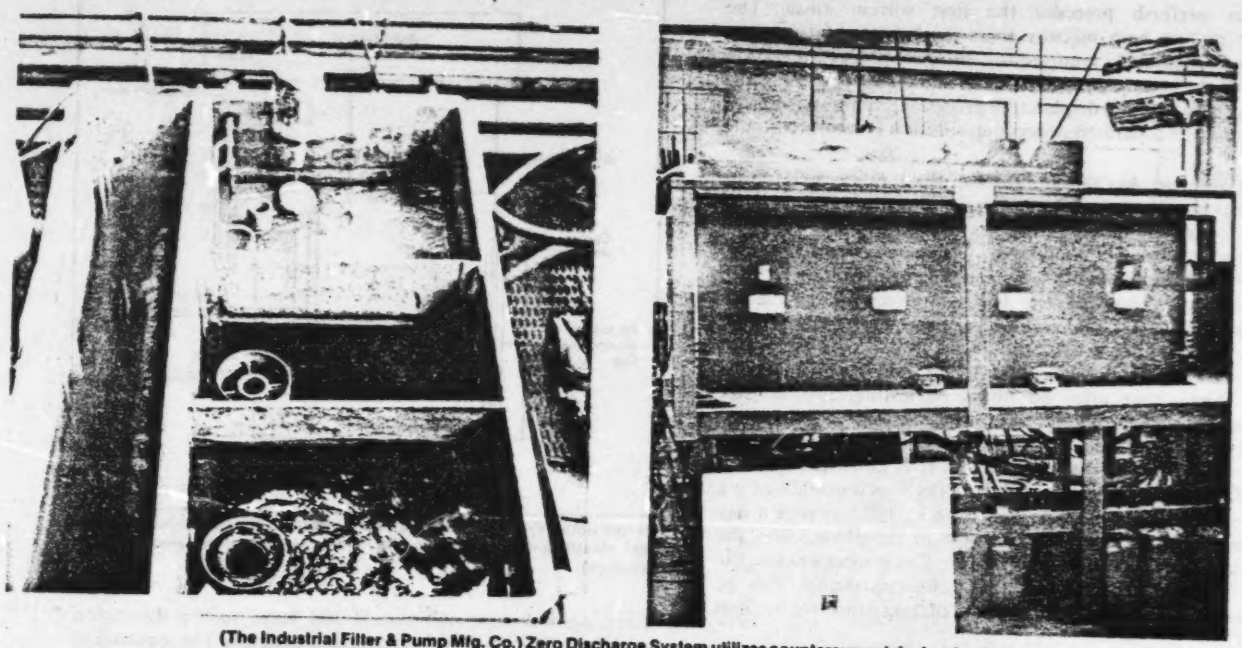


Electrodialysis units operating on Watts-type nickel line at Risdon Manufacturing Co., Waterbury, CT.



(The Industrial Filter & Pump Mfg. Co.) Zero Discharge System utilizes countercurrent rinsing, leading separation techniques and displacement by immiscible fluids. (Left) Immiscible fluid, perchloroethylene, is separated, then collected at top of tank. (Right) ZDS demonstrated on chrome bumper plating line.

cyanide solution in pilot work. The lack of success in this particular application should not discourage attempts to apply electrodialysis for both pollution control and metal recovery.

NEWER MEMBRANE TECHNIQUES

Another membrane technique that is near commercialization for treatment and metal recovery from rinsewaters is Donnan dialysis. In Donnan dialysis the driving force is a difference in concentration and not electrical or another form of energy. The process involves passing a wastewater solution containing metal ions (e.g., nickel) through the inside of small diameter tubes fabricated from a cation exchange membrane. A suitable regenerant (e.g., sulfuric acid) is passed over the outside of the tubes countercurrent to the waste stream flow. The metal ion can be easily concentrated to over ten times its original concentration in the waste stream. The system produces slightly acidified water rather than pure water, and a use for the acidic water must be found if neutralization and discharge is to be avoided.

Application of Donnan dialysis as a tool for metal recovery has been prevented by the lack of a stable ion-exchange membrane. The development of Nafion® perfluorinated resin by DuPont provides a cation exchange membrane of exceptional chemical resistance and good mechanical properties. A full-scale prototype unit, employing DuPont's Nafion® polymer membrane, is presently being tested for nickel recovery at the Seaboard Metal Finishing Co., West Haven, CT under EPA Grant No. 804655.

Bend Research of Bend, OR has developed a process called "Coupled Transport Membranes" for the treatment of metal containing wastes. This process uses "liquid membranes" which consist of a solution of a complexing agent dissolved in an organic solvent and encapsulated in a special micro-porous membrane, usually polypropylene. The metal is complexed at one surface of the membrane, transported in this form through the membrane simply by its concentration gradient, and released at the opposite surface by a change in pH. The complexing agent is thus freed and diffused back through the membrane to the wastewater side where the process can be repeated.

In a recently completed project with EPA/AES support (Grant No. 804682) preliminary evaluation of this technique was carried out.[40] It was demonstrated that the metals could be removed from the simulated rinsewaters and concentrated on the downstream side, from which it could be removed or recycled to the plating bath. Based only on preliminary data, very attractive economics are claimed for chromate and copper treatment. However, the process is only in its initial stage of development.

SOLVENT-BASED SYSTEMS

Aside from a few applications in which closed-loop recovery can be achieved by countercurrent rinsing alone, some technique must be used to separate the dissolved plating chemicals from the rinsewater. The leading techniques for making the separation are reverse osmosis, evaporation and ion exchange. Recently, the Industrial Filter and Pump Mfg. Co., Cicero, IL developed a new rinse-and-recovery system that utilizes a combination of countercurrent rinsing, the leading separation techniques, and adds a further element of displacement by immiscible fluids.[41] This system, called ZDS™ (Zero Discharge System), uses a two-stage solvent spray rinse followed by a single stage aqueous immersion rinse. A small

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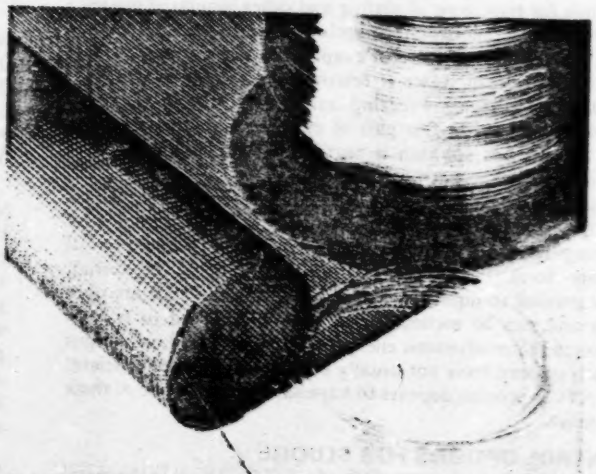


Du Pont's "Nafion" perfluorosulfonic acid products in sheet and tubing forms.

aqueous preflush precedes the first solvent rinse. The solvent/plating bath mixture from the bottom of the spray tanks is continuously removed to a compact processing station where phase separation is made. The solvent is returned to the spray service to again displace the processing solution from the parts, and the separated processing solution is returned to the bath.

Displacement by the immiscible fluid (here, perchloroethylene) provides an additional stage of rinsing which permits either fewer countercurrent stages or smaller ion exchange, evaporative, and RO equipment. Thus, the system provides complete rinsing in less space, time and cost. By continuously purifying and recycling the baths, appreciable savings in operating, chemical, and water costs can be realized.

The ZDS™ system has been demonstrated on a simulated chrome plating bumper line under EPA Grant No. 803723. This study shows that after 80 hours of testing, the level of hexavalent chrome in dragout was less than 2 ppm. The complete cost of one ZDS™ module was $46,400 as of May 1976, with a 10-year life expectancy. It is estimated that the power consumed is the same for the ZDS™ as it would be for a countercurrent rinsing system. Assuming 100 bumpers a day (500 bumpers a week) are run through the plating line, the operational cost per bumper is $0.168. This project was specific to chromium recovery, but the technique should also be applicable to a variety of other metal plating processes (rack or barrel).

The use of immiscible organic solvents for extraction of heavy metals from waste effluents is gaining broader industrial importance. In Sweden four solvent extraction processes have been developed and at least two applied in large treatment plants for recovery of metals from industrial metal waste, either solid or liquid.[42]

Dr. McDonald of Texas Southern University, Houston, TX has completed a laboratory investigation of solvent extraction procedures for removal of metals from metal finishing wastes under EPA Grant No. 803332.[43] A mixture of Alamine 336, a high molecular weight amine, and xylene was used to extract selectively or simultaneously chromium, cadmium, and zinc. The effective wastewater to solvent ratio was 100:1 and a single extraction removed 90 per cent of chromium, 98 per cent of cadmium and 83 per cent of zinc. The metals were stripped from the organic phase with over 99.5 per cent efficiency with sodium hydroxide. The regenerated reagent can be recycled and reused without any loss of extraction efficiency. The procedures are reproducible, rapid and relatively simple. The economic feasibility of the process could be determined in a pilot scale operation. Particularly the simultaneous extraction of the three metals shows promise for utilization of small metal finishing facilities.

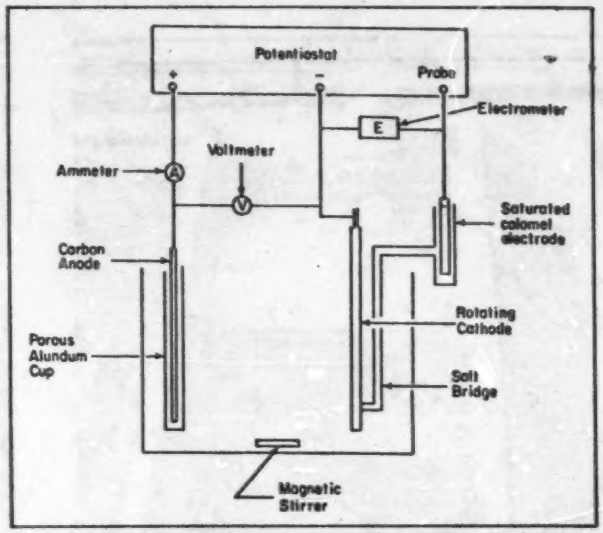
FREEZING

One last process remains to be discussed as a possible future technique for treatment of plating and other industrial wastes. As noted earlier, energy consumption has been considered one of the deterrents to the use of evaporation for concentration. The evaporation of water is relatively energy intensive: 540 Kcal/l (8115 Btu/gal). Freezing, on the other hand, requires only 80 Kcal/l (1193 Btu/gal) of energy. And, fortuitously, when an aqueous solution is partially frozen, pollutants are concentrated in the unfrozen portion.

This fact is the basis for a purification process developed by AVCO Corporation in which a solution of waste is cooled by the evaporation of a low boiling hydrocarbon (propane) until crystals form.[44] The gaseous hydrocarbon is recovered, recompressed to liquify it, and recycled. The crystals are pure water and can be melted, rinsed, and discharged or reused. Although thermodynamic energy requirements are low, designs of such systems have not usually been economical or efficient. The AVCO process appears to have surmounted some of these problems.

CONTROL OPTIONS FOR SLUDGE

Considering the present status of waste treatment in the metal finishing industry, one should not leave such a discussion without a few words about the sludge problem. The sequence of conventional alkaline chlorination followed by single stage pH adjustment to an "optimum" pH, addition of a coagulating aid, and clarification/settling is capable of removing a soluble heavy metal to significantly less than 1 ppm. However, if several metals are present in a mixed waste, an average or "optimum" pH is most often used. This, coupled with a common ion effect, often increases the total and individual soluble ion concentrations significantly. Two stage pH adjustment or Permutit's Sulfex process can improve soluble metal precipitation significantly. In either case, conventional clarification techniques can be expected to leave perhaps 5-15 ppm of suspended solids composed of the various metal hydroxides.



(From Battelle) Schematic for apparatus used for constant cathode potential electrowinning (proposed for metal recovery from electroplating sludges).

The final result of clarification, filtration, etc. is in every case a sludge, usually of mixed metal hydroxides. These are currently trucked to landfills or, where permitted, disposed of in the ocean along with other sludges. In the near future, neither of these options may be available. Further, these sludges contain metals which could be valuable—if they could be separated and concentrated. EPA's R&D program has long recognized the potential value of these materials and the problems their recovery would eliminate. Although various metal refining techniques, including electrowinning, have been proposed for metal recovery from electroplating sludges, none of these routes appears to be practical or economically attractive at this time.

As part of a comprehensive study of electroplating sludges carried out by Battelle,[45] two techniques for extracting metals from sludge were developed: sulfuric acid solubilization of metal hydroxides and precipitation of calcium sulfate, followed by filtration to obtain a clear pregnant liquor; and solution in ammonia-ammonium carbonate solution, followed by filtration to produce a pregnant liquor.

Preliminary cost estimates based on small batch operations showed that the sulfuric acid leach process for mixed sludges can be economical only when carried out on a large and continuous scale. The minimal feed rate would have to be in the range of 900-2270 kg (2,000 to 5,000 lb) of sludge (dry basis) solids per day. Ammonium carbonate leaching would be applicable only on even larger scale. If either of the two processes are used, the actual recovery of metals should be achieved by electrolysis or electrowinning from the pregnant liquor. Of course, if recovery were done in a central facility, sludge transportation would add to the costs.

A pilot plant study (EPA Grant No. 803787) has recently been completed on the ammonium carbonate leaching

process.[46] This study confirmed that metal recovery from mixed sludges is neither technically nor economically feasible at this time.

Recovery of a metal from a single metal sludge, even in the form of metal compounds, can prove economical and be done on-site. For example, Lancy's integrated system[1] can be designed to provide for metal recovery from the generated sludge. The segregated treatment of a single metal waste results in a concentrated metal sludge which, when washed of contaminants and redissolved, can be returned to the manufacturing process. This approach closes the metal discharge loop and eliminates sludge disposal. As a matter of fact, such systems are available today, but the data on their economics are uncertain.

EPA is presently demonstrating such a nickel recovery process designed by Lancy Laboratories under Grant No. 804434 to the Huntington Division of the Houdaille Industries, Inc., Huntington, WV. Nickel will be recovered from carbon bath treatment purification sludges in the form of nickel sulfate and possibly also in the form of nickel carbonate. These two nickel compounds will be returned to the manufacturing process. True economics of the process and evaluation of the purity of regenerated nickel compounds will be documented as part of this demonstration.

CONCLUSION

It can be reiterated that our work has attempted to address the most pressing problems, as reflected by the efforts of the industry, its associations, and its suppliers—all of whom are, in the final analysis, the sources of most of the technology.

Reexamining the dynamic picture that exists, several areas where continuing R&D will be needed can be identified. These include the destruction of tightly complexed cyanide ions; improved removal of heavy metal-containing suspended solids; and considerably more attention to the recovery and reuse of plating chemicals in general. The increased use of chelated metals as a means of eliminating or reducing cyanide must be viewed with some caution, since such chelating agents as EDTA, NTA, etc. may create their own toxicity problems and, further, may interfere with the precipitation of the metals or even contribute to their redissolution downstream.

General questions related to metal sludge deserve more attention, both to develop readily removable sludges and to find environmentally safe disposal sites or, preferably, procedures for metal recovery and reuse either within the electroplating industry or by other industries. As the cost of many of these metals increases, recovery routes should become more attractive. It may be desirable today to designate "storage areas" for such metal wastes so that they are readily retrievable for chemical recovery at a later date.

The EPA is well aware of the complexity and diversity of the electroplating industry and of the technical and economic problems inherent in applying pollution abatement technology to its processes. The R&D program, through careful assessment of the industry and its problems and development and demonstration of various new technologies such as those noted in the foregoing discussion, is attempting to assist the industry in meeting its current and future environmental responsibilities.

Anyone interested in participating in grant and contract programs concerning adding process alternatives leading to pollution abatement, water pollution control, air pollution control or solid waste control is invited to contact Mr. George Thompson, Chief of the Metals and Inorganic Chemicals Branch of the Industrial Environmental Research Laboratory in Cincinnati, OH for further information.

REFERENCES

28. L. T. Rozelle, "Ultrathin Membrane for Treating Metal Finishing Effluents by Reverse Osmosis," EPA-12010 DRH, U. S. EPA, Cincinnati, OH, November, 1971.
29. R. J. Petersen and K. E. Cobian, "New Membranes for Treating Metal Finishing Effluents by Reverse Osmosis," EPA-600/2-76-197, U. S. EPA, Cincinnati, OH, October, 1976.
30. R. G. Donnelly et al., "Treatment of Electroplating Wastes by Reverse Osmosis," EPA-600/2-76-261, U. S. EPA, Cincinnati, OH, September, 1976.
31. K. J. McNulty et al., "Reverse Osmosis Field Test Treatment of Watts Nickel Rinsewaters," EPA-600/2-77-039, U. S. EPA, Cincinnati, OH, February, 1977.
32. K. J. McNulty et al., "Reverse Osmosis Field Tests Treatment of Copper Cyanide Rinsewaters," EPA Grant No. 800945. Final report in printing.
33. H. J. Davis et al., "PBI Reverse Osmosis Membrane for Chromium Plating Rinsewater," EPA Grant No. 803620. Report under review.
34. K. J. McNulty et al., "Treatment of Metal Finishing Wastes by Reverse Osmosis," Amer. Institute of Chemical Engineers Symposium, Atlantic City, NJ, 1976.
35. K. J. McNulty, Abcor, Inc., letter to G. S. Thompson, U. S. EPA, January 18, 1977.
36. Osmonics, Inc., private communication to Mary Stinson, U. S. EPA, June 24, 1977.
37. S. B. Tuwiner, "Investigation of Treating Electroplaters' Cyanide Waste by Electrodialysis," EPA-R2-73-287, U. S. EPA, Cincinnati, OH, December, 1973.
38. J. L. Eisenmann, "Recovery of Nickel from Plating Bath Rinsewaters by Electrodialysis," 64th Technical Conference, American Electroplaters' Society, Los Angeles, CA, June, 1977.
39. G. W. Bodamer, "Electrodialysis for Closed Loop Control of Cyanide Rinsewaters," EPA Grant No. S-803304. Final report in printing.
40. H. K. Lonsdale et al., "Coupled Transport Systems for Control of Heavy Metal Pollutants in Metal Finishing Solutions," EPA Grant No. 804682. Report under review.
41. R. W. Crain et al., "Environmental and Economic Advances for Metal Finishing Processes," 64th Technical Conference, American Electroplaters' Society, Los Angeles, CA, June, 1977.
42. H. Reinhardt, "Solvent Extraction for Recovery of Metal Waste," *Chemistry and Industry*, 5, 210 (March 1, 1975).
43. C. W. McDonald, "Removal of Toxic Metals from Metal Finishing Wastewaters by Solvent Extraction," EPA Grant No. 803332. Report under review.
44. R. J. Campbell and D. K. Emmerman, *Industrial Water Engineering*, 9, No. 4, 38 (June/July 1972).
45. A. B. Tripler Jr., R. H. Cherry Jr., and G. R. Smithson Jr., "Reclamation of Metal Values from Metal Finishing Waste Treatment Sludges," EPA-670/2-75-018, U. S. EPA, Cincinnati, OH, April, 1975.
46. J. B. Hallowell, E. S. Bartlett and R. H. Cherry Jr., "Ammonium-Carbonate Leaching of Metal Values from Water Treatment Sludges," EPA Grant No. 803787. Final report in printing.

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Mary K. Stinson is a Chemical Engineer with EPA's Industrial Environmental Research Laboratory-Ci in Edison, NJ. She received her M. S. in Chemical Engineering in Poland and a M. S. in Water Resources Science from the University of Michigan. During her three years in EPA's Metals and Inorganic Chemicals Branch, she has been Project Officer for a number of R&D projects. She is a member of the AES Newark Branch.

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